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[54] Title of the invention: Friction stir welding process

[57] Abstract

[Problem to be solved] To propose a friction stir welding process for obtaining a uniform joint quality from the start of the joint to the end, and also a high productivity.
[Solution] Friction stir welding process for continuously assembling two workpieces by making the end of a friction stir welding tool describe a relative path along the joint line, the tool being rotated and held in a penetrated configuration, characterized in that it regulates, practically uniformly, the supply of heat to the workpieces by acting on the rotation speed of the welding tool, the speed of advance of the welding, external heating and cooling means or means of heating and cooling the welding tool.

Claims

[Cl. 1] Friction stir welding process for continuously assembling two workpieces by making the end of a friction stir welding tool describe a relative path along the joint line, the tool being rotated and held in a penetrated configuration, characterized in that it regulates, practically uniformly, the supply of heat to the workpieces to be welded, from the start of the joint to the end.

[Cl. 2] Friction stir welding process according to Claim 1, which regulates the supply of heat to the workpieces to be welded by varying the rotation speed of the friction stir welding tool.

[Cl. 3] Friction stir welding process according to Claim 1, which regulates the supply of heat to the workpieces to be welded by varying the speed of advance of the welding.

[Cl. 4] Friction stir welding process according to Claim 1, which regulates the supply of heat to the workpieces to be welded by heating or cooling the workpieces from the outside.

[Cl. 5] Friction stir welding process according to Claim 1, which regulates the supply of heat to the workpieces to be welded by heating or cooling the friction stir welding tool.

[Cl. 6] Friction stir welding process according to any one of Claims 1 to 5, which regulates, during the welding, the supply of heat to the workpieces to be welded by measuring, during welding, the temperatures of the joint or of the zone close to the joint of the workpieces and by being based on the values thus measured.

[Detailed description]

[0001] The present invention relates to a welding process for continuously assembling two workpieces by making the end of a friction slow welding tool describe a relative path along the joint line, the tool being rotated and held in a penetrated configuration.

[0002]

[Prior art] Friction stir welding recently appeared as a new means for joining together metallic materials other than by conventional welding or brazing processes. As described in the patent application filed under the publication number 1995-505090, this process benefits from the plastic flow that the materials of the workpieces to be welded undergo owing to the effect of the pressure and the friction heat that are generated locally when a probe (a cylindrical pin) made of a material that is harder than that of the workpieces to be welded and placed in rotation bears frictionally against these workpieces. It follows that said probe can penetrate into the workpieces to be welded and be moved therein while being kept in this configuration.

[0003] To give an example, in the case of assembling two metal plates (1) end to end, as illustrated in Figure 1, a friction stir welding tool is used that has the shape of a cylindrical body (20), on the end of which there is a probe (21) having a protruding profile. While the

tool (2) is being rapidly rotated, it is forcibly pressed onto the initial point of the weld line (L) so as to make the probe (21) penetrate, and said probe is moved in the direction indicated by the arrow along this weld line (L). The pressure and the friction heat that are generated in front of the progressing probe (21) cause plastic flow of constituent materials of the metal plates (1) (1), which materials then progressively migrate towards the rear of the probe (21) and mix together. The sudden cooling and solidification, resulting from the loss of friction heat in this rear zone, have the effect of welding the two metal plates (1) (1) after friction and mixing of the materials.

[0004] There are many advantages of this process: the temperature at which the metallic materials undergo plastic flow is firstly substantially below that of the melting point, which means that this process can be classified in the category of solid-phase assembly processes; in addition, the supply of heat to the workpieces through this process is reliable; finally, no stresses resulting from shrinkage upon solidification are generated. The assembly is therefore less sensitive to formation of cracks and to strains generated by the thermal distortion in the zone close to the joint. Moreover, as shown in Figure 1, it is very possible to produce this assembly using a treatment head placed at a fixed position and by moving the workpieces, instead of moving the friction stir welding tool (2).

[0005] Conventionally, the treatment parameters are chosen according to the nature of the constituent materials of the workpieces to be welded, their thickness, the characteristics of the friction stir welding tool, the rotation speed of said tool, the speed of advance of the welding or the depth of penetration of said tool. These treatment parameters remain constant from the start of the joint to the end.

[0006]

[Object of the invention] Conventional friction stir welding processes also have however a number of drawbacks, in particular when welding workpieces that tend to retain heat more easily, owing to their geometry or the type of material. Thus, as the supply of heat to the welded parts gradually increases, as the operation progresses, differences in quality may appear between the start of the joint and the end. These differences are most particularly appreciable when welding along an orbital path relative to small-diameter workpieces (W), such as cylindrical bars or tubes with a diameter of less than 60 mm, as shown in Figure 2. This scenario poses consequential problems from the practical standpoint. Another disadvantage of the conventional friction stir welding processes is the low productivity due to the not insignificant time that elapses before either the tool or the workpieces can be advanced, insofar as it is necessary firstly to make the end of the tool penetrate into these workpieces.

[0007] Faced with the abovementioned situations, the objective of the present invention is to provide a friction stir welding process for obtaining a uniform joint quality, from the start of the joint to the end, and with a high productivity.

[0008]

[Proposed solution] To meet the abovementioned objectives, the friction stir welding process according to Claim 1 is characterized in that it regulates practically uniformly the supply of heat to the workpieces to be welded, from the start of the joint to the end. In other words, by making the supply of heat to the workpieces uniform it is possible to limit the local variations in the state of the joint that are caused by the variations in heat flow and thus reduce the changes in friction-stir welded structure caused by the hardening of materials undergoing plastic flow. This process is particularly well suited for the orbital welding of small-diameter workpieces (W), such as cylindrical bars or tubes with a diameter of less than 60 mm. However, it is not limited just to this situation.

[0009] Among the solutions proposed for regulating, as described above, the supply of heat to the workpieces, the present invention provides several variants: Claim 2 proposes to vary the rotation speed of a friction stir welding tool; Claim 3 proposes to vary the speed of advance of the welding; Claim 4 proposes heating or cooling the workpieces from the outside; and finally, Claim 5 proposes heating or cooling the friction stir welding tool part.

[0010] Furthermore, the invention according to Claim 6 proposes an embodiment according to any one of Claims 1 to 5, which consists in measuring, during welding, the temperature of the joint or of zones close to this joint and in being based on the values thus measured in order to regulate the supply of heat to the workpieces during welding.

[0011]

[Mechanism of the invention] In the friction stir welding process according to the present invention, the supply of heat to the workpieces is regulated so as to be uniform from the start of the joint to the end, the main factors contributing to said supply of heat in this friction stir welding process being: a) the geometry of the friction stir welding tool; b) the rotation speed of said tool; c) the speed of advance of the welding; d) the depth of penetration of said tool (contact area between tool and workpieces). Now, if the geometry of the friction stir welding tool a) and the depth of penetration of said tool d) are determined by the thickness or the type of joint of the workpieces to be welded, the rotation speed of said tool b) and the speed of advance of the welding c) may very well be used as factors for regulating the supply of heat.

[0012] In other words, if the supply of heat proves to be insufficient, it is possible either to increase the rotation speed of the tool or reduce the speed of advance of the welding so as to increase the amount of heat delivered. In contrast, and again in the same scenario, this supply of heat may be reduced by decreasing the rotation speed of the tool or by increasing the speed of advance of the welding. However, there is an admissible range within which the friction stir welding can be carried out, said range being characterized by a ratio between the rotation speed and the speed of advance of the welding, so that it is recommended that these two parameters be varied within this range in order to regulate the supply of heat.

[0013] To vary the rotation speed of the tool, the rotation of the main spindle of the friction stir welding machine may also be regulated. Likewise, to vary the speed of advance of the welding, either the speed of movement of this main spindle may be regulated, in the case of

welding by moving the tool part, or the speed of movement of said tool may be regulated, in the case of welding by moving the workpiece part.

[0014] Moreover, within the context of this invention, as means of regulating the supply of heat to the workpieces, it is possible to use a method of heating or cooling the workpieces, and also a method of heating or cooling the friction stir welding tool part. To heat the workpieces, several means may be used, such as hot-air blowers or heaters. To cool the workpieces, the latter may be brought into contact with a low-temperature fluid and the rate of heat dissipation may be increased by heat exchange therewith. However, nothing precludes the use of other heating or cooling means that differ from those mentioned.

[0015] To heat the tool part, it is possible to provide a jacket (3) surrounding the cylindrical body (20) of the friction stir welding tool (2), inside which jacket (3) a heater (4) will be placed, as the diagram in Figure 3(a) illustrates. It is also possible to opt for the solution illustrated by the diagram in Figure 3(b), in which a heating fluid is made to circulate inside this same jacket (3). Several solutions may be adopted for cooling the tool part: it is possible for a low-temperature fluid to circulate inside the jacket of Figure 3(b) or for a coolant to circulate inside the tool using a method with a central through-hole, such as those used in machine tools.

[0016] Among the methods using these regulating means, so as to regulate the supply of heat to the workpieces practically uniformly from the start of the joint to the end, we will distinguish those consisting in defining an off-line regulating index from those consisting in correcting the supply of heat according to the state of the welding by an in-line feedback control.

[0017] In the first, off-line type of method, the state of the joints of specimens that have actually undergone a friction stir welding operation are compared, in particular through observation of the structures, so as to determine by an experimental trial-and-error method the optimum conditions for supplying heat to each of the zones, the space separating the start of the joint from the end being suitably segmented. Once these optimum conditions are known, the method may be based on them so as to regulate the supply of heat during welding using one of the abovementioned means.

[0018] In the second, in-line type of method, and as the diagram in Figure 4 illustrates, the temperature of the joint or of the zone close to the joint of the workpieces (W) is continuously measured during welding using a thermometric unit. Each measured value is fed into a control unit that determines a compensating amount of heat on the basis of the difference between the measured value and a predetermined internal setpoint value. At the same time, the control unit transmits an actuating signal to the unit for actuating said regulating means, said signal being intended to compensate for the heat supply. It is therefore the operation of this actuating unit that allows the supply of heat to the workpieces (W) to be corrected during welding. It is just as possible to correct the supply of heat to the workpieces (W) during welding by being based on the aforementioned temperature measurements and by manually

adjusting the unit for actuating said regulating means, without therefore using this automatic control loop. Although a contactless thermometric device, based in particular on temperature sensors that measure thermal radiation, constitutes a preferred embodiment, it is also possible to use a contact-type thermometric device.

[0019] By making the supply of heat to the workpieces uniform, it is possible to limit the local variations in the state of the joint that are caused by the variations in heat flow and thus reduce the changes in friction-stir welded structure caused by the hardening of materials that have undergone plastic flow. This solution provides a joint quality that is uniform from the start of the joint to the end and offers excellent results in particular in the case of orbital welding of cylindrical bars or small-diameter tubes.

[0020] In the case when a method regulating the supply of heat to the workpieces by varying the rotation speed of the welding tool is used, the increase in this rotation speed makes it possible both to speed up the penetration of this tool and to start the welding operation earlier. This time saved, in making the end of said tool (probe) penetrate the workpieces and then starting either the tool or the workpieces to advance so as to weld them, the tool being in penetrated configuration, makes it possible to increase productivity. Moreover, in the case when a method for regulating the supply of heat to the workpieces by varying the speed of advance of the welding and the rotation speed of said tool is used, the particular external devices intended for heating or cooling become superfluous. This is advantageous in terms of equipment costs.

[0021]

[Implementation examples] The workpieces to be assembled are tubes made of 6063-T5 aluminium, measuring 50 mm in diameter with a wall thickness of 4 mm. As friction stir welding tool, we used a probe 4 mm in diameter. We welded these tubes using orbital welding, maintaining a constant joint temperature of about 480°C, the rotation speed of said tool being 1300 rpm at the start of the joint and 1100 rpm at the end of the joint. Comparing the structures of the welded workpiece joints, it was possible to confirm that a uniform friction-stir welded structure was obtained over the entire length of the joint and that there were no local differences in quality.

[0022]

[Comparative examples] We used a friction stir welding tool and tubes identical to those of the aforementioned implementation example. The rotation speed of this tool was kept constant at 1100 rpm from the start of the joint to the end. The friction stir welding operation was carried out along an orbital path. During the operation, the temperature of the joint was modified, going from 460°C at the start of the joint to 490°C at the end of the joint. By comparing the structures of the welded workpiece joints, it was shown that there were large differences in the friction-stir welded structure between the start and the end of the joint, and also that the joint quality was non-uniform.

[0023]

[Advantages of the invention] The friction stir welding process according to Claim 1 regulates, practically uniformly, the supply of heat to the workpieces to be welded, from the start of the joint to the end. It thus makes it possible to obtain a friction-stir welded structure that is constant over the entire length of the welded joint and a uniform joint quality. This process is particularly well suited for orbital welding of cylindrical bars or small-diameter tubes.

[0024] The above friction stir welding process according to Claim 2 regulates the supply of heat to the workpieces by varying the rotation speed of the friction stir welding tool. Thus the use of special external devices, such as means for regulating said supply of heat via heating or cooling, becomes superfluous. This therefore represents an advantage in terms of equipment costs, while improving the productivity by increasing the speed, either in penetration of the end of said tool or in starting the tool or the workpieces to advance, the tool being in penetrated configuration.

[0025] The above friction stir welding process according to Claim 3 regulates the supply of heat to the workpieces by varying the speed of advance of the welding. Thus the use of special external devices, such as means for regulating said supply of heat by heating or cooling, becomes superfluous, and this therefore represents an advantage in terms of equipment costs.

[0026] The above friction stir welding process according to Claim 4 or 5 either heats or cools the workpieces or the friction stir welding tool. It thus makes it possible to regulate, practically uniformly, the supply of heat to the workpieces from the start of the joint to the end.

[0027] The above friction stir welding process according to Claim 6 regulates the supply of heat to the workpieces by a direct feedback step based on temperature values measured during welding and characterizing the joint or a zone close to this joint. Thus, it is possible to correct the supply of heat according to the state of the welding and to make this supply of heat uniform from the start of the joint to the end.

[Brief description of the drawings]

[Figure 1] Perspective view showing the assembly of metal plates by a friction stir welding process.

[Figure 2] Cross-sectional view of the assembly of tubes by a friction stir welding process.

[Figure 3] Implementation examples according to the present invention of a means of regulating the heat supplied to the workpieces, Figure 3(a) being a simplified cross-sectional view of a friction stir welding tool of the heating type and Figure 3(b) a simplified cross-sectional view of the same tool for heating or cooling by means of a fluid.

[Figure 4] Schematic view showing a means of regulating the supply of heat to the

workpieces according to the friction stir welding process of the present invention.

[Notations]

1: metal plate; **2**: friction stir welding tool; **20**: cylindrical body; **21**: probe (end); **3**: jacket; **4**: heater; **W**: workpieces.

Translation of the illustrations

[Figure 1] - Page (4) at the bottom, first figure from the left
[Figure 2] - Page (4) at the bottom, second figure from the left
[Figure 3(a)] - Page (4) at the bottom, second figure from the right
[Figure 3(b)] - Page (4) at the bottom, first figure from the right

[Figure 4] - Page (5)

[top left]	Actuating unit
[top right]	Control unit
[bottom right]	Thermometric unit